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THE UNDERSEA HABITAT AS A SPACE STATION ANALOG: EVALUATION OF RESEARCH AND TRAINING POTENTIAL

NASA/University of Texas Technical Report 85-7

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1 October, 1985

NCC2-286

This research was sponsored by NASA Co-operative Agreement ~~NCC2-282~~, Robert L. Helmreich, Principal Investigator. Special thanks are due to Ian G. Koblick and James W. Miller for providing access to diving facilities and discussion of research and operational issues. Thanks are also due to Carlos R. Canales for assisting in the evaluation of dive sites and habitat.

(NASA-CR-180342) THE UNDERSEA HABITAT AS A SPACE STATION ANALOG: EVALUATION OF RESEARCH AND TRAINING POTENTIAL (Texas Univ.) 20 p Avail: NTIS HC A02/MF A01 CSCL 05H

N87-27405

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Introduction

The magnitude and complexity of sustaining a manned Space Station for long periods of productive work have lead to a search for relevant analogs which can provide databases on behavioral issues expected in such an environment. It is obvious that the best analog of a space station is an operational space station – and both the U. S. during the Skylab missions and the Russians for the last decade have had such stations. Unfortunately, however, neither of these provides a useful database. In the case of the U.S. endeavor, as in all space missions, no systematic behavioral data were collected and only fragmented, anecdotal reports on adjustment are available. The Russians have also failed to make public useful psychological data, although anecdotal reports indicate that serious problems have arisen (Chaiken, 1985; Bluth, 1981).

Lacking data from the micro-gravity environment of space, investigators have focused on earthly analogs such as undersea habitats, submarines, Antarctic stations, and oceanographic research vessels as representing many, but not all, of the factors relevant to a space station (e.g. Miller, 1983; Stuster, 1984; Christensen & Talbot, 1985; Schoonhoven, 1985; Holloway, in preparation; National Research Council, Committee on Space Biology and Medicine, in preparation).

The present report provides an evaluation of the utility of undersea habitats for both research and training on behavioral issues for the Space Station. Additionally, to make the

discussion more concrete, the feasibility of a particular habitat, La Chalupa, will be examined.

Space Station/Habitat Commonalities

Extensive psychological research programs have been conducted during three American undersea habitat projects, Project SEALAB II conducted by the U.S. Navy during 1965 and Projects TEKTITE I and TEKTITE II sponsored jointly by the Navy, NASA, and the Department of the Interior during 1969-1970, and these will serve as the referents for comparisons with space station operations. Both undersea and space habitation represent living and working in a total environment that is restricted in area and hazardous. Both are inescapable: Astronauts can return to earth only by means of a transport spacecraft while Aquanauts, once saturated with breathing gas at the ambient pressure of the habitat, must undergo lengthy decompression to avoid decompression sickness. The combined living and workspace in both is restricted, raising problems of privacy, territoriality and conflict over use of resources. Extra-vehicular activity (EVA) from a spacecraft is closely paralleled conceptually by excursion diving from the habitat. The most striking dissimilarity, of course, is in the fact that spacecraft operate in a micro-gravity environment leading both to different physiological responses and to different utilization of the physical space in the vehicle.

The most important commonalities appear to be in the area of social and organizational psychological factors. These are the issues that are most likely to have a major influence on the

productivity and adjustment of crewmembers on long-duration space missions.

Meaningful Work. Of paramount importance is the fact that participants are performing real work which is personally, professionally relevant and, as such, perceive themselves as true participants in the endeavor rather than as research subjects. This is in sharp contrast to simulation studies where participants' activities serve the purpose of generating research data. In such studies the lack of personal involvement of subjects often leads to results highly different from those obtained from personally involved crews. For example, research conducted during the 1960's on small groups in isolation (military subjects confined in windowless suites of rooms with only research tasks to perform) suggested, from the high incidence of subjects failing to complete several weeks of confinement due to high perceived "stress" and from outbursts of overt hostility, that psychological adjustment would be a continuing and major problem in confined groups (Haythorn & Altman, 1966). These results differ profoundly from the generally excellent adjustment shown by Aquanauts and Astronauts.

These contrasting results have been interpreted in terms of the costs and rewards found in the two settings (Radloff & Helmreich, 1968). While the objective costs, in terms of danger and discomfort, are usually low in simulations, the objective and subjective rewards for participation are also typically low and the absolute values of these factors may strongly influence motivation, performance, and adjustment. The cost-reward model is shown in Figure 1.

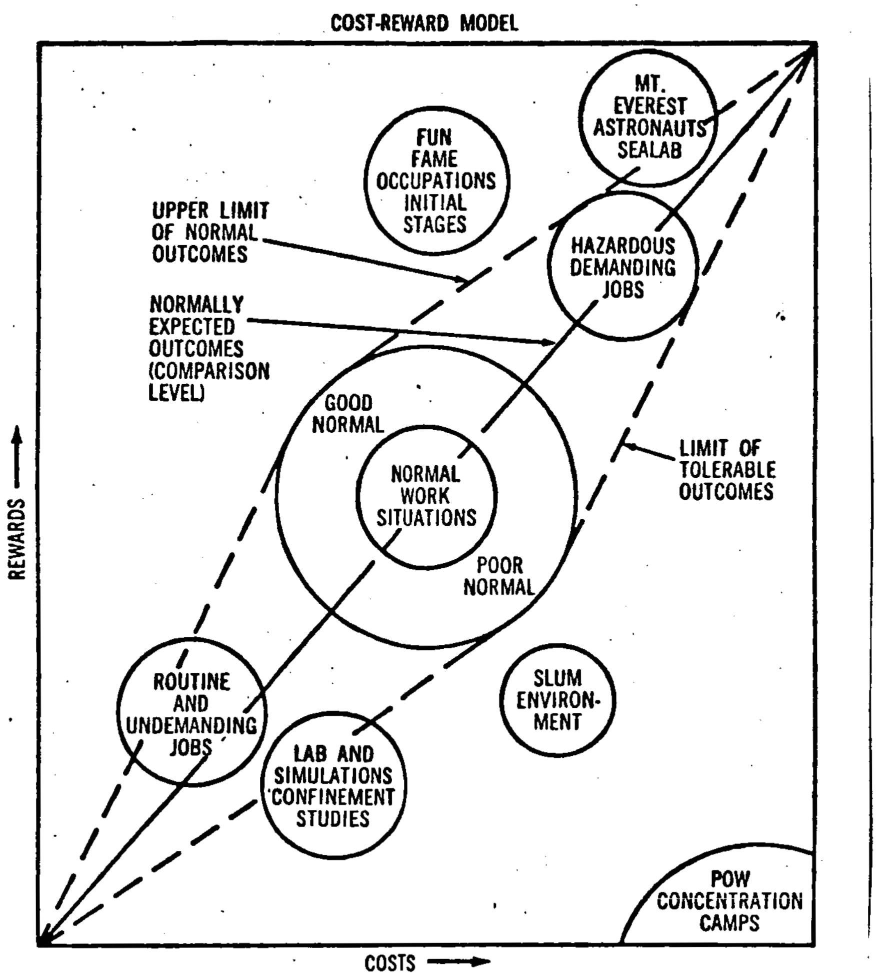

Figure 1. The Cost-Reward Model (from Radloff & Helmreich, 1968).

The preceeding discussion is not meant to negate the importance of simulations as means of evaluating person-machine interfaces and in training and evaluating mission candidates as these are obviously critical tasks best accomplished in such a setting. Rather it is arguing that social and organizational issues are best explored in settings where individuals are highly involved and where performance outcomes are personally relevant to participants.

Heterogeneous Groups and Goals. One of the given assumptions for the Space Station is the fact that participants will come from much more heterogeneous backgrounds than, for example, the Mercury Astronauts. This cohort was composed of white, male, military test pilots who underwent long periods of training as a group before flight. Space Station crewmembers will be both male and female, are likely to reflect highly diverse educational and vocational backgrounds, and will probably be involved in very different projects which may compete for resources within the station. Additionally, groups will undoubtedly not have the long periods of common training time before missions. This type of crew composition and formation has great potential for interpersonal conflict, especially when participants are confined in a highly restricted environment for long periods of time.

Group composition in both SEALAB and TEKTITE reflected such heterogeneity. Crews in SEALAB were composed of military enlisted and officer divers and civilian scientists with a range of education from less than high school to doctoral degrees. Tasks ranged from marine biological and biochemical research to salvage

work. Similarly, TEKTITE crews each contained several subgroups of scientists working on different projects and an engineer charged with habitat maintenance. Crews only assembled as a whoe a few days prior to the beginning of their mission. Both males and females participated in TEKTITE, but females served on a separate, all female crew.

It should be noted that the composition of the current STS crews, including Astronauts, Mission Specialists, and Payload Specialists, is fairly heterogeneous. However, mission durations are short and no systematic behavioral research is being conducted either during training or on operational missions.

Crew Autonomy. In space missions to date as well as both undersea projects, the issue of control of mission activities by ground based authorities versus crew self-determination has been a major source of conflict. Some researchers have referred to this as the "peripheral paranoia" of isolated groups. In the case of longer missions in the Space Station, this is a potentially serious factor that requires explication.

Leadership. Leadership of a heterogeneous group with multiple goals in a total environment will be a critical issue in the Space Station as it was for leaders in both SEALAB and TEKTITE. The common features of these undersea environments and space make this a key issue for evaluation.

Privacy and Personal Space. The necessarily limited volume of both space and undersea structures makes privacy and personal space important issues, especially for long missions. In both undersea settings privacy was a behavioral issue. There is no question about its importance for the Space Station.

Work Design and Role Sharing. Both space and undersea environments have in common the fact that in addition to primary scientific or operational tasks, a substantial amount of time must be devoted to maintenance of the vehicle and maintenance of the crew's nutritional needs as well as the mundane duties of housekeeping. How these duties, as well as operational requirements, are assigned can be critical to the acheivement of high productivity and good morale. In the SEALAB missions, maintenance and housekeeping were shared among crewmembers with no formal organization. In TEKTITE, an engineer with primary responsibility for habitat maintenance was included on each crew. Food preparation responsibilities, however, evolved as a function of individual preferences.

While not exhaustive, the above list gives an indication of the extent to which central interpersonal issues are shared in these diverse environments.

Non-U. S. Approaches

Undersea habitat activities have by no means been limited to the U. S. Indeed, as documented by Miller and Koblick (1984), a total of sixty-five habitats have been or are operational, representing efforts by seventeen nations. The largest number of habitats belong to the Soviet Union with almost half of the total (29) coming from Eastern Bloc countries. The United States has developed the second largest number, fourteen.

More relevant to the question of space/undersea parallels is information recently obtained by one of the authors (RLH) from

personal communications with a Soviet psychologist and a French diving authority. Boris Lomov is head of the Soviet Institute of Psychology and a central figure in aviation and space psychology. Lomov stated that the Soviets have extensively used undersea activities as part of their space program. He did not, however, indicate whether the undersea work consisted of research, Cosmonaut training, or both.

Jacques Rougerie, a French naval architect, designer, and diver indicated that a four-person undersea habitat of his design was currently under construction in France and would be used for long duration acclimitization and training work with French space candidates. He did not indicate whether or not there would be a significant behavioral research component in this activity.

Psychological Research In SEALAB and TEKTITE

As noted, extemsive psychological research was conducted in both SEALAB and TEKTITE. In SEALAB, studies included an array of performance evaluations including visual, auditory, and psychomotor skills (Miller, 1966) and continuous systematic observation of individual and group behavior and performance. These were conducted during each of three ten-day missions conducted by a crew of ten Aquanauts (Pauli & Clapper, 1967; Radloff & Helmreich, 1968). Extensive pre- and post-mission debriefing interviews were also conducted.

In TEKTITE, a major study of habitability was conducted including evaluations of the habitat, measures of mood, and leisure activities (Nowlis, 1972). The largest psychological effort involved continuous systematic observation of the in-

habitat behavior of the ten five-person Aquanaut teams (Helmreich, 1971). An emphasis of this program was the refinement of methodologies for systematic behavioral observation.

Behavioral findings included significant relationships between performance and group cohesiveness, hostility between Aquanaut crews and surface controllers, temporal changes in performance and shifts in sleep/work cycles. Other significant data included the effects on performance of role-sharing and the performance impact of partial crew rotation. Significant individual differences in performance and adjustment were also isolated and related to personal characteristics. The fact that a longitudinal record of behavior was obtained allowed for much more detailed analyses than the usual single event study in these areas.

A critical point in the behavioral research in these projects is that they were conducted on a non-interfering, unobtrusive basis. This research strategy, which was dictated by operational concerns, has both advantages and disadvantages. On the positive side, the subjects perceived their primary mission as the conduct of professional work and did not feel constrained by the psychological investigation. On the negative side, however, a number of extremely important issues involving mission organization and structure, role relationships, and crew composition could not be explored. In evaluating potential benefits from further undersea research, the possibility of imposing crucial experimental manipulations while preserving an unobtrusive data collection strategy will be discussed.

Research and Training Potential of Future Habitat Projects

The central question in determining whether additional work in undersea habitats would be useful in planning future Space Station operations is whether such research would provide new, valid data on issues likely to influence the success of space operations. The answer is an unequivocal yes <u>if a pool of Aquanaut candidates who would find the environment uniquely suitable for performing meaningful work can be located</u>. This point will be discussed following specific research questions.

Four factors make the prospect of conducting additional research in this setting particularly appealing. One is that there have been substantial advances over the last fifteen years in hardware (micro-computer and video) required for data acquisition and in analytic techniques for large, time-series databases. The second is that there have been a number of theoretical developments in organizational and personality psychology that generate testable research hypotheses applicable to the space environment. The third is that it would be possible to conduct multiple missions within the same environment giving a more solid statistical base to obtained results. The fourth, growing out of the third, is that a <u>quasi-experimental methodology</u> could be employed across missions allowing the manipulation of significant group and organizational factors while giving participants basic autonomy in the conduct of their undersea work. The list of specific areas where profitable research may be conducted touches on all of the commonalities discussed above and several additional topics. The following are

particularly important.

Crew Autonomy and Leadership. Using the quasi-experimental approach, it would be possible to vary the degree of ground control exerted over the crew and to examine effects on group processes and performance. Similarly, different degrees of authority for the leadership role can be imposed and studied. With heterogeneous crews and multiple tasks, these issues are especially critical.

Work Design and Role Relationships. It would also be possible to vary work design for subgroups experimentally. Of particular interest is whether maintenance and housekeeping functions should be specialized or shared by all participants. The effects on group relations of creating interdependence in task accomplishment between subgroups could also be investigated. This restricted work setting appears to be well-suited for investigations of the psychology of work in total environments.

Personality-Situation Interactions. Recent developments in personality and achievement motivation theories could be studied in the context of confined groups to provide useful information both for selection and for crew composition.

Privacy and Leisure Needs. While the physical configuration of a habitat cannot precisely parallel that of a micro-gravity space vehicle, the types of privacy needs and leisure preferences of crews can be investigated. In the same manner, the dynamics associated with mixed-sex crews can be examined.

Monitoring of Psychological State. A particular need in long duration missions is a means of monitoring the psychological

state of crewmembers. The undersea setting should be an excellent environment in which to develop and evaluate monitoring systems.

Evaluation of Training. It is likely that intensive, short-term training in effective crew coordination will be required for missions involving crews without a long common training history. This is a form of training which is rapidly being adopted for airline and military transport crews (e.g. Lauber & Foushee, 1982). With replicated missions, it should be possible to assess the impact on crew behavior of various training techniques. During the course of initial research, it could also be determined whether or not such a setting might prove useful for training of actual Space Station crews.

Further Refinement of Observational Methodologies. The relatively stable undersea envorionment should be an outstanding setting for further refinement of observational methodologies for assessing individual and group performance. This line of investigation would be complementary to efforts underway with air transport crews and should apply equally to operational shuttle missions.

Optimal Research Strategy. Rather than sponsoring research by a single Principal Investigator, the optimal strategy for obtaining as much usable and applicable data as possible should be to sponsor multiple investigators with differing research foci to collect data during the same missions. By forcing this type of collaboration from the inception of a large-scale project, NASA can not only insure the collection of meaningful datasets but can also stimulate the kind of collaboration that is ultimately necessary to generate data truly useful in the

planning and operation of successful operations in the Space Station.

The Requirement for Meaningful Work

As we have stressed, the validity of space-related research conducted in undersea habitats hinges on the ability to select crews with meaningful work best performed in a saturation environment. The chances of accomplishing this appear to be excellent. A variety of marine research endeavors fit well into shallow underwater settings, with work best accomplished by workers who can spend unlimited daily time at the work site. Federal funding for undersea habitat operations, largely administered through the National Oceanographic and Atmospheric Administration (NOAA) has been severely restricted in recent years, with the result that there is far greater demand than availability for access to habitat resources.

Several possible research areas are relevant to possible space station operations. These include the development and utilization of undersea robotics and expert systems and research on pharmacology. Certainly the crew interaction with expert systems will be a critical operational issue in future space missions. Other topics, less directly applicable to space include underwater ecology and biochemistry and the development of an artificial gill for underwater breathing. Overall, it should be possible to attract a substantial number of projects which would lend fidelity to extended periods of confined work and living underwater.

La Chalupa as a Possible Test Site

La Chalupa was chosen for preliminary evaluation for several reasons. These include: a history of successful operations; the possibility of rapid, economical activation; a practical crew size (5 or 6) relevant to Space Station configuration; simplicity of operation and logistic support; and a possible dive site relatively free of weather restrictions on operations.

La Chalupa was completed in 1972 as part of a program sponsored by the Marine Resources Development Foundation and the government of Puerto Rico. It is designed to operate with a crew of five at depths up to 30.5 meters and distances up to 16 km from shore. The support structure for the habitat consists of a submersible barge containing the habitat chambers. Because of the design, Aquanauts can decompress on the surface in the living quarters or on the ocean floor in the working compartment. The primary working and living quarters consist of two 2.4 X 6m cylindrical chambers separated by a non-pressurized 3 x 6 m wet room for work and access to the sea. The layout of the habitat portion of La Chalupa is shown in Figure 2. As the diagram shown, the quarters are spartan and cramped, but not conceptually dissimilar to many possible Space Station configurations. The layout allows considerable flexibility in equipment installed and the ability to make modifications, such as adding additional modules, to meet specific mission requirements and/or to test the impact of particular spatial arrangements and spatial configurations.

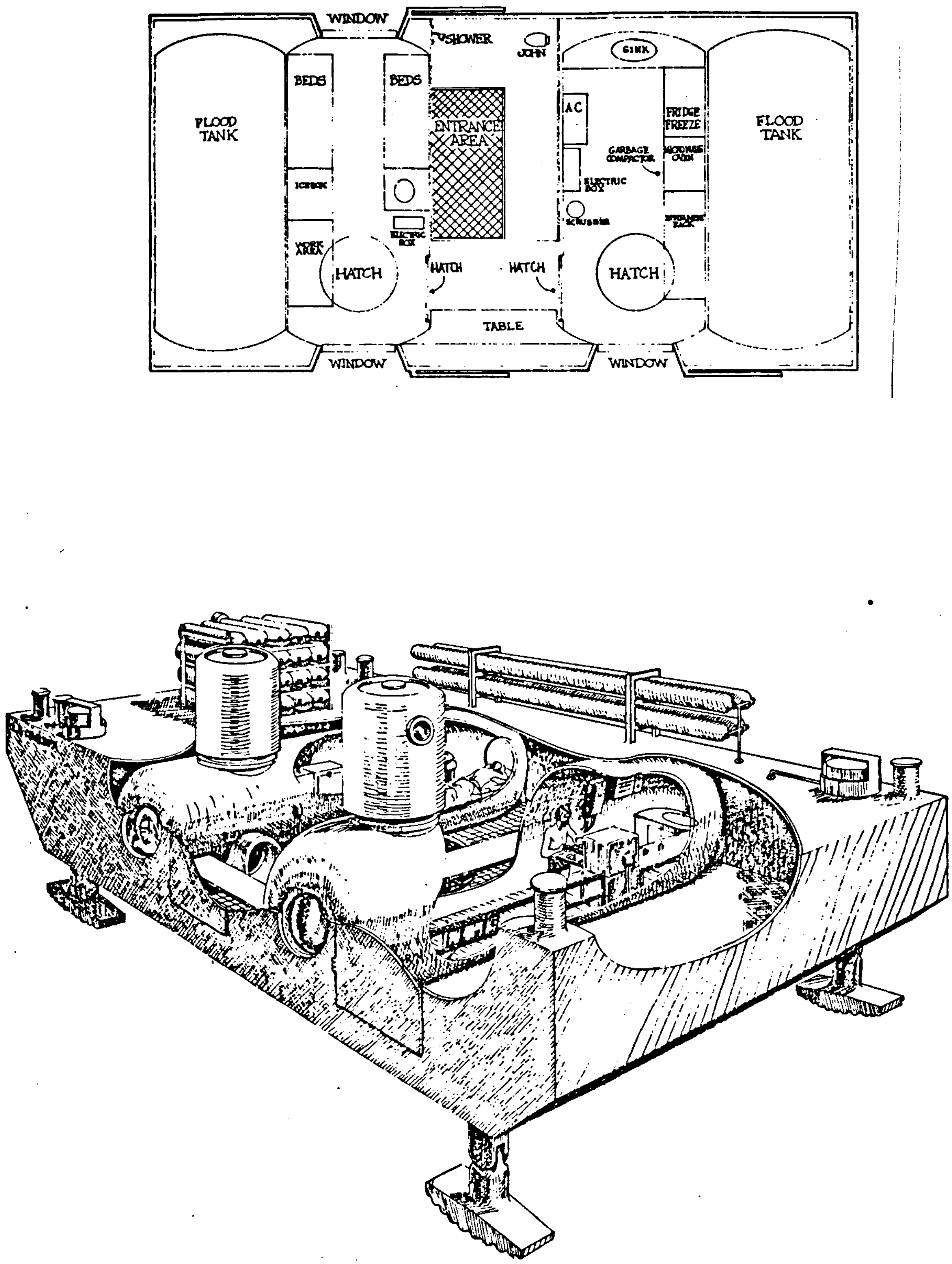

Figure 2. Schematic drawings of La Chalupa habitat (from Miller & Koblick, 1984).

The habitat has a substantial operational history. It has been employed in nine saturation missions during which a total of forty-two scientists spent over 1600 hours in the water and made over 1700 dives ranging in length from five minutes to six hours.

The habitat has not been operational since the mid-nineteen seventies. However, it has been refurbished and is currently in storage in Fort Lauderdale, Florida. Given the time pressure to obtain valid behavioral data prior to Space Station IOC, the fact that this habitat, unlike other U. S. vehicles, could be rapidly operational, makes it a desirable candidate for preliminary research. Given the mobility of the habitat, a number of dive sites could be employed. For logistic and safety reasons, one viable site would be a salt-water lagoon on the Atlantic side of Key Largo with a bottom depth of approximately 10 meters. Such emplacement would allow shore-based support and easy access to air and land transportation while at the same time providing a researchable underwater environment relatively protected from adverse weather.

Conclusion

The analysis presented above suggests that many unresolved questions relating to human behavior in the planned Space Station could be investigated in this type of environment and that such research could be mounted in a relatively short time frame at fairly low cost. Given the need for early, reliable, and valid data on behavioral and organizational questions that may be critical to the success of extended space operations, it is recommended that further investigation of the feasibility of

such a project be undertaken. For such research to have maximum utility, considerable urgency should be attached to beginning investigations at the earlies possible time. It is also possible that such a project could be conducted in collaboration with other government agencies, such as the National Oceanographic and Atmospheric Administration and the Office of Naval Research, that have a direct interest in work under the sea.

It should also be noted that research undertaken in such a setting would also make a contribution extending beyond application to Space Station operations. The psychological data would address more global questions of selection, training, and organizational design while the actual work performed by research subjects would contribute to further exploitation of the ocean floor.

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